Perspectives on Self-Disinfecting Photocatalytic Surfaces

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Self-disinfecting surfaces are of considerable interest to counter bioburden in healthcare settings. In such settings, high touch surfaces pose a significant platform for the spread of infection from patient to patient. As pathogens become more resistant to antibiotics, resulting infections resulting become more of a threat. One study of high touch surfaces found that the three most common surfaces for infection transmission are bed rails, bed tables, and IV pumps [1]. Although periodic and terminal cleaning protocols are well developed, disinfection is often incomplete. A variety of adjunct technologies, including UV light (254 nm) disinfection, short wavelength visible light (405 nm) [2], and antimicrobial surface technologies [3] have been developed to improve disinfection outcomes. Each technique has strengths and weaknesses. Our opinion is that conventional cleaning and adjunct technologies have a place in a comprehensive approach to managing surface borne pathogens in critical healthcare settings and that a variety of complementary techniques may be brought to bear on the problem for a more robust solution.

Photocatalysis represents a complementary mode of action for self-disinfecting surfaces. The most common photocatalyst, titanium dioxide (TiO_2), is a wide bandgap semiconductor that forms electron-hole pairs under illumination. The electrons and holes generate reactive oxygen species (ROS) by the interaction of the illuminated surface with oxygen and moisture in the air. This process is shown schematically in Figure 1. ROS are broadly antimicrobial – they are effective against viruses, bacteria, and spores. A classic paper on this effect was published by Nakano [4] who showed efficacy for both Gram-positive and Gram-negative bacteria. TiO_2 is generally photoactive in the ultraviolet spectrum, particularly UVC (254 nm). Considerable work has been undertaken to enable activation in the visible spectrum, i.e., wavelengths greater than 400 nm. Many approaches involve the use of dopants that modify the bandgap of titania to allow generation of electrons and holes in the visible range or that take advantage of heterogeneous interfaces that result in charge separation [5,6].

For most settings where ambient lighting is to provide photocatalytic activation, the mode of illumination should be considered. Traditional fluorescent lighting has considerable output in the blue-green wavelengths, which are known to suppress generation of melatonin in the body, disrupting sleep. This 'Melanopic spectrum' peaks at 490 nm, with a full width at half maximum (FWHM) of approximately 80 nm [7]. Illumination from light emitting diodes (LEDs) offers the opportunity to engineer light source spectral output. Several manufacturers now produce LED lights with significant output in the violet, low output in the Melanopic spectrum, and balanced output at longer wavelengths. These lights are ideal for photocatalytic activation in a hospital setting from the perspective of shorter wavelength activation and the absence of illumination that has a negative impact on sleep.

Hospital high touch surfaces may be modified with TiO_2 via an applied coating or by incorporating the photocatalyst directly into the substrate. We are applying the former to medical devices and to high touch surfaces, particularly those identified above. There are numerous considerations for a successful surface modification, including maintaining efficacy, wear resistance, degradation, and tactile behavior. For the high touch surface application, we are creating a composite with an organic polymeric matrix. A critical building block of the coating is the photocatalyst. Photocatalytic behavior may be assessed by spectroscopic characterization of a species sensitive to the ROS created by the illumination of the photocatalyst. Figure 2 shows the decrease in the concentration of an aqueous solution of such a species, phenol, in contact with a TiO_2-based photocatalyst as a function of time under illumination at 405 nm. The photocatalyst may be modified to improve the level of activity under visible light. Figure 3 shows the inactivation of *Bacillus subtilis* PS533 spores using a cast film of a TiO_2-based photocatalyst with 365 nm light. These results show the promise of the photocatalytic approach for hard-to-kill pathogens such as spores, which have high resistance to almost all common decontamination regimens.

References

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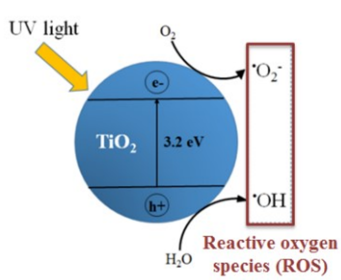

Figure 1. Photocatalytic mechanism over TiO_2. UV light promotes an electron from the valence band (VB) to the conduction band (CB), leaving a hole in the VB and an electron in the CB.

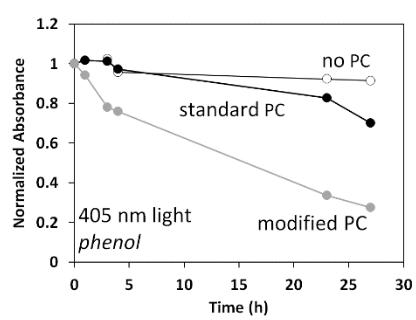

Figure 2. Photocatalytic decomposition of phenol in contact with a standard TiO_2-based photocatalyst (PC) and a modified PC under 405 nm light.

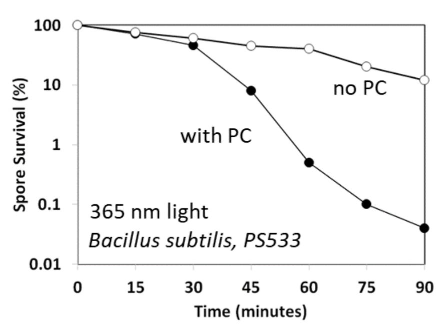

Figure 3. Photocatalytic inactivation of *Bacillus subtilis* spores using a cast film of a standard TiO_2-based photo-catalyst (PC) illuminated with 365 nm light.